

Non-central HBT

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in collaboration with
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|-----|------------------|-------------------------------------|
| TH: | U.A. Wiedemann | Phys. Rev. C <u>57</u> (1998) 265 |
| | M.A. Lisa et al. | Phys. Lett. B <u>489</u> (2000) 287 |
| Ex: | AGS E895 | Phys. Lett. B <u>496</u> (2000) 1 |
| | STAR prelim. | |

Introduction

v_2

reproduced by hydro

HBT

not reproduced by hydro

$$\lambda_{mfp} = 0$$

$$\lambda_{mfp} \sim R_{\text{system}}$$

depends on geometry but
does not measure geometry

measures geometry

$$S(x, k)$$

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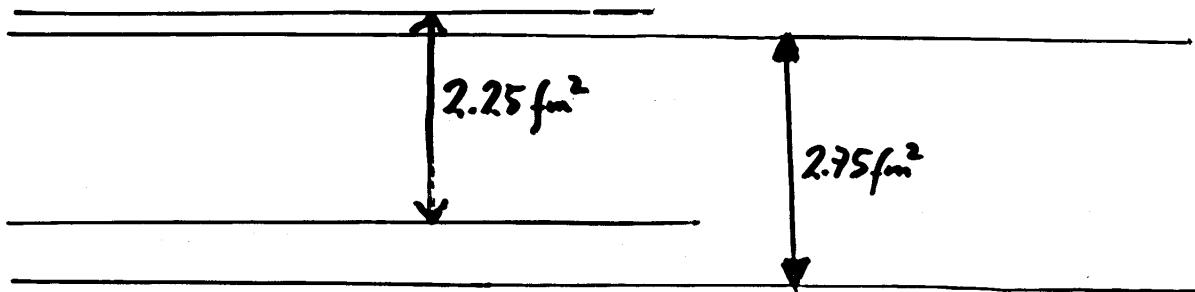
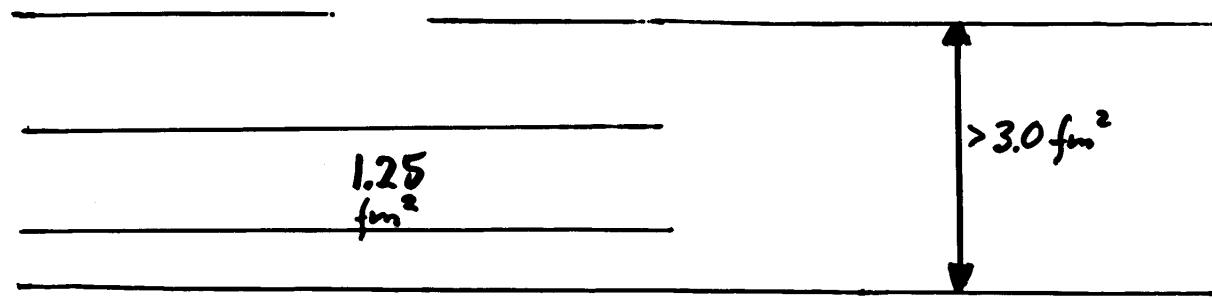
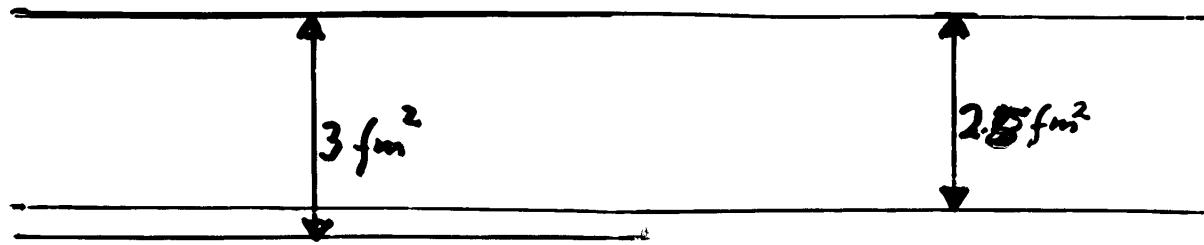
not sensitive to
freeze-out

determined at
freeze-out

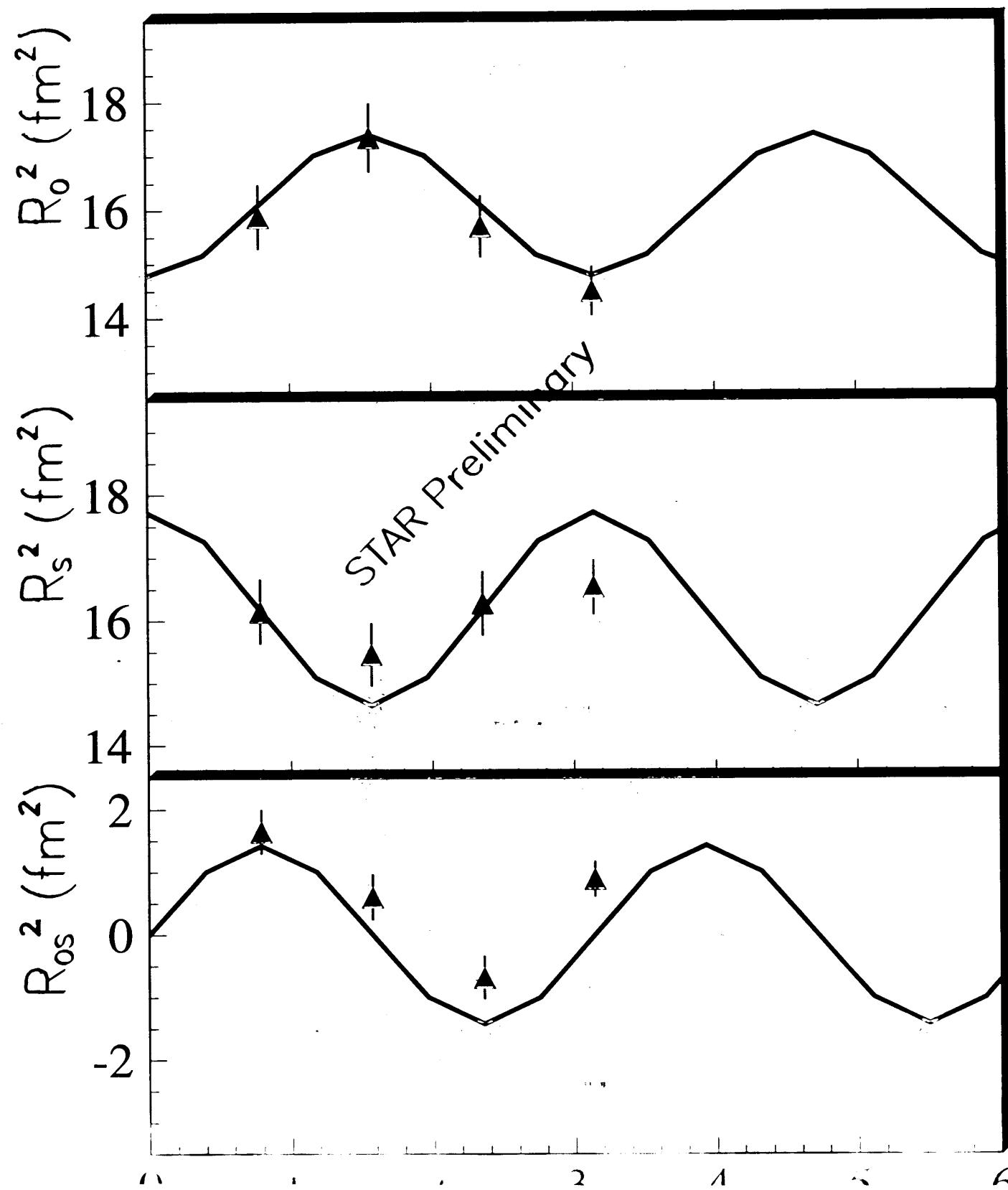
Motivation for non-central HBT:

to learn about the physics

connecting $\lambda_{mfp} = 0$ to $\lambda_{mfp} \sim R$

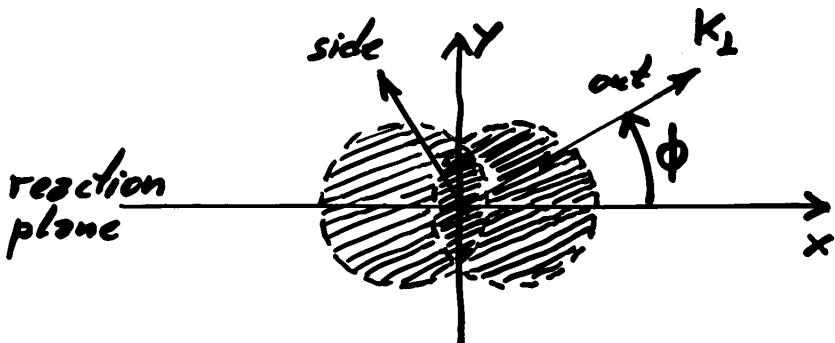


$$R_{ij}^2(\phi) = R_{ij,0}^2 + R_{ij,2}^c \cos(2\phi) + R_{ij,2}^s \sin(2\phi)$$



The Formalism

$$C(K, q) = 1 + \frac{\left| \int d^3x S(x, K) e^{iq \cdot D_4 x} \right|^2}{\left| \int d^3x S(x, K) \right|^2}$$



space-time averages: $\langle f \rangle(K) \equiv \frac{\int d^3x f(x) S(x, K)}{\int d^3x S(x, K)}$

$$R_s^2(K_L, \phi, Y) = \langle \tilde{x}^2 \rangle \sin^2 \phi + \langle \tilde{y}^2 \rangle \cos^2 \phi - \langle \tilde{x} \tilde{y} \rangle \sin 2\phi$$

$$\begin{aligned} R_o^2(K_L, \phi, Y) = & \langle \tilde{x}^2 \rangle \cos^2 \phi + \langle \tilde{y}^2 \rangle \sin^2 \phi + \langle \tilde{x} \tilde{y} \rangle \sin 2\phi \\ & - 2\beta_L \langle \tilde{z} \tilde{x} \rangle \cos \phi - 2\beta_L \langle \tilde{z} \tilde{y} \rangle \sin \phi + \beta_L^2 \langle \tilde{z}^2 \rangle \end{aligned}$$

$$\begin{aligned} R_{os}^2(K_L, \phi, Y) = & \frac{1}{2} \sin 2\phi (\langle \tilde{y}^2 \rangle - \langle \tilde{x}^2 \rangle) + \langle \tilde{x} \tilde{y} \rangle \cos 2\phi \\ & + \beta_L \langle \tilde{z} \tilde{x} \rangle \sin \phi - \beta_L \langle \tilde{z} \tilde{y} \rangle \cos \phi \end{aligned}$$

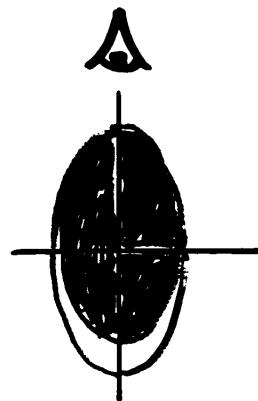
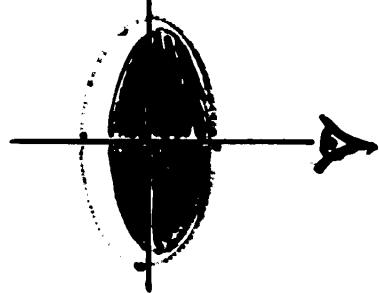
$R_L \dots$

$R_{ol} \dots$

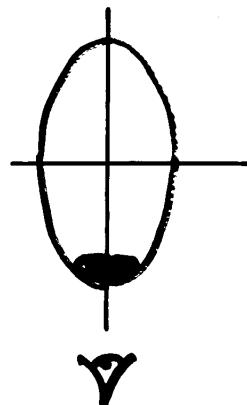
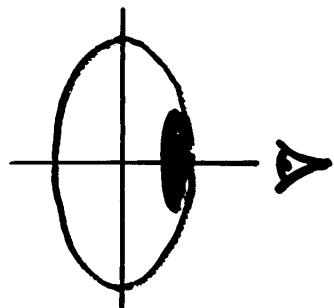
$R_{el} \dots$

Explicit vs. implicit ϕ -dependence.

Low K_\perp



high K_\perp



Implicit ϕ -dependence of $\langle \tilde{x}_\mu \tilde{x}_\nu \rangle$.

$$\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi) = \sum_{n=0}^{\infty} \langle \tilde{x}_\mu \tilde{x}_\nu \rangle_n^c \cos(n\phi) + \langle \tilde{x}_\mu \tilde{x}_\nu \rangle_n^s \sin(n\phi)$$

characterizes dynamical correlations
vanishes for a ϕ -independent source

Symmetry constraints

▲ Mirror sym. w.r.t. reaction plane

$$\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi) = -\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(-\phi) \quad \text{either } \tilde{x}_\mu = \tilde{y} \text{ or } \tilde{x}_\nu = \tilde{y}$$

$$\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi) = \langle \tilde{x}_\mu \tilde{x}_\nu \rangle(-\phi) \quad \tilde{x}_\mu, \tilde{x}_\nu \neq \tilde{y}$$

$$\langle \tilde{t}^2 \rangle(\phi) = \langle \tilde{t}^2 \rangle(-\phi)$$

▲ Point sym. at mid rapidity

$$\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi) = -\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi+\pi) \quad \text{either } \tilde{x}_\mu = \tilde{t} \text{ or } \tilde{x}_\nu = \tilde{t}$$

$$\langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi) = \langle \tilde{x}_\mu \tilde{x}_\nu \rangle(\phi+\pi) \quad \tilde{x}_\mu, \tilde{x}_\nu \neq \tilde{t}$$

$$\langle \tilde{t}^2 \rangle(\phi) = \langle \tilde{t}^2 \rangle(\phi+\pi)$$



not valid at forward rapidity

HBT radius parameters combine explicit and implicit ϕ -dependence

$$R_{s,2}^c = \frac{1}{2} (\langle \tilde{y}^2 \rangle_0 - \langle \tilde{x}^2 \rangle_0) + \frac{1}{2} (\langle \tilde{y}^2 \rangle_2^c + \langle \tilde{x}^2 \rangle_2^c)$$

$$R_{o,2}^c = -\frac{1}{2} (\langle \tilde{y}^2 \rangle_0 - \langle \tilde{x}^2 \rangle_0) + \frac{1}{2} (\langle \tilde{y}^2 \rangle_2^c + \langle \tilde{x}^2 \rangle_2^c) \\ + \beta_1 (\langle \tilde{x}\tilde{t} \rangle_1^c - \langle \tilde{y}\tilde{t} \rangle_1^s) + \beta_2^2 \langle \tilde{t}^2 \rangle_2^c$$

$$R_{os,2}^s = \frac{1}{2} (\langle \tilde{y}^2 \rangle_0 - \langle \tilde{x}^2 \rangle_0) + \frac{1}{2} \beta_1 (\langle \tilde{x}\tilde{t} \rangle_1^c - \langle \tilde{y}\tilde{t} \rangle_1^s)$$

General Conclusions: U.A.W PRC 57 (1998) 265

1. $-R_{o,2}^c = R_{os,2}^s = R_{s,2}^c$

indicates absence of dynamical correlations

2. $R_{o,2}^c + 2R_{os,2}^s = R_{s,2}^c$

expected to hold in presence of dynamical correlations
(deviation sensitive to ϕ -dependence
of temporal correlations \Rightarrow)

$\Rightarrow R_{s,2}^c + R_{o,2}^c = \langle \tilde{y}^2 \rangle_2^c + \langle \tilde{x}^2 \rangle_2^c$

Experimental data: Blast wave model

$$R_{o,2}^{c^2} = -3 \text{ fm}^2 \quad -2.5 \text{ fm}^2$$

$$R_{s,2}^{c^2} = 1.25 \text{ fm}^2 \quad 3.0 \text{ fm}^2$$

$$R_{os,2}^s = 2.25 \text{ fm}^2 \quad 2.75 \text{ fm}^2$$

1. check: $-R_{o,2}^{c^2} = R_{os,2}^s = R_{s,2}^{c^2}$

significant deviations

⇒ intrinsic ϕ -dependence

data contain dynamical information

2. check: $R_{o,2}^{c^2} + 2R_{os,2}^s = R_{s,2}^{c^2}$

$$\text{exp: } -3 + 2(2.25) \approx 1.25$$

$$\text{blast: } -2.5 + 2(2.75) = 3.0$$

good agreement

⇒ intrinsic ϕ -dependence dominated by

$$\boxed{\frac{1}{2}(\langle \tilde{y}^2 \rangle_2^c : \langle \tilde{x}^2 \rangle_2^c)}$$

The sign of $\langle \tilde{y}^2 \rangle_z^c + \langle \tilde{x}^2 \rangle_z^c$.

$$R_{s,2}^{c^2} + R_{o,2}^{c^2} = \langle \tilde{y}^2 \rangle_z^c + \langle \tilde{x}^2 \rangle_z^c$$

① blast wave:

$$\langle \tilde{x}^2 \rangle_z^c + \langle \tilde{y}^2 \rangle_z^c = 0.5 \text{ fm}^2 > 0$$

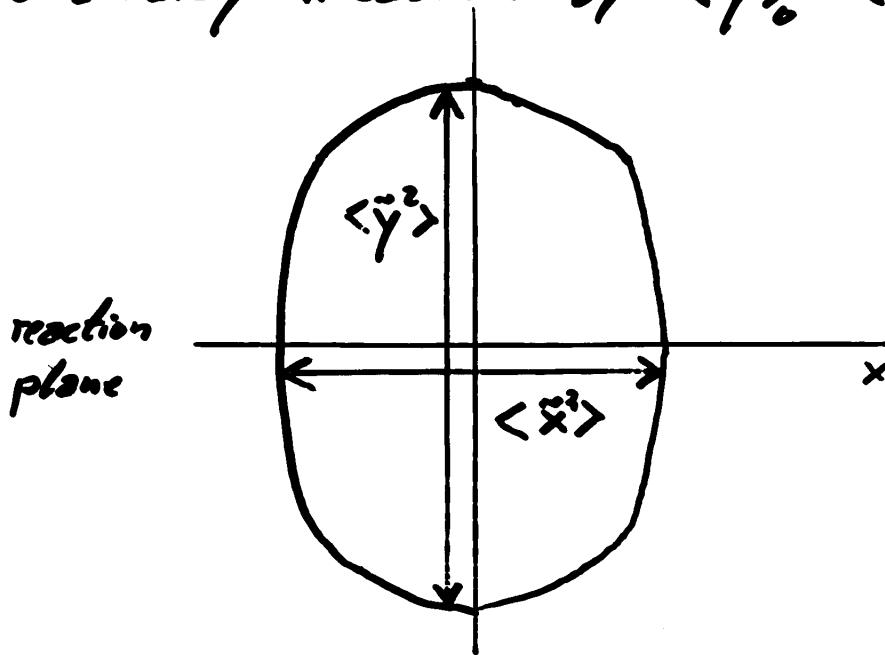


② STAR precision:

$$\langle \tilde{x}^2 \rangle_z^c + \langle \tilde{y}^2 \rangle_z^c = -1.75 \text{ fm}^2 < 0$$

⇒ ① and ② show
qualitatively different dynamical correlations

▲ Eccentricity measured by $\langle \tilde{y}^2 \rangle - \langle \tilde{x}^2 \rangle_0$

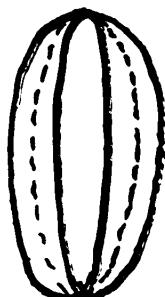


$$\langle \tilde{y}^2 \rangle - \langle \tilde{x}^2 \rangle_0 > 0 \Rightarrow \text{out of plane homogeneity region}$$

▲ What is measured by $\langle \tilde{y}^2 \rangle_2^c + \langle \tilde{x}^2 \rangle_2^c$?

Example:

$\Delta \phi = 90^\circ$ ---- denotes average



$$\langle \tilde{y}^2 \rangle_2^c = 0$$

$$\Delta \phi = 0 \quad \langle \tilde{x}^2 \rangle_2^c < 0$$

homogeneity region smaller for $\phi = 0$

$$\Rightarrow \langle \tilde{y}^2 \rangle_2^c + \langle \tilde{x}^2 \rangle_2^c < 0$$

more to come: B. Tomaszik + U.A.W.

What's next?

- ▲ K_\perp -dependence of R_o^2, R_{os}^2, R_s^2 2 bins may do?
 - intrinsic ϕ -dependence expected to decrease for decreasing K_\perp
 \Rightarrow handle on separating geometrical and dynamical information
- ▲ ϕ -dependence of R_{el}^2, R_{sl}^2 @ RHIC
 - dominant ϕ -dependence at AGS,
measuring the "tilt" of emission region w.r.t. beam axis
 \Rightarrow STAR measurement important for energy dependence
NA49 may have a contribution here?
- ▲ Rapidity-dependence

p.s. always quote accuracy of EbyE reconstruction of reaction plane